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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF PV MODULE FOR BETTER EFFICIENCY USING POROUS MEDIA

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ABSTRACT

Jordan severely lacks enough sources of energy, which causes a decline in its economic level, this is due to the high cost of production of electricity using imported fossil fuels, However, it is found that during operation, a Photovoltaic cell in a PV system only converts a portion of the sun light it receives into electrical energy while the remaining converts into heat which is normally lost. To maintain desired operation temperature of PV cells with best performance, a back surface cooling channel with porous media as a cooling-system. The cooling channels are packed with glass porous medias with sphere diameter of 10mm. Three different cooling channels thickness of 3cm, 5cm and 7cm with three water volume flow rate of 1L/min, 1.5L/min and 2L/min are used in the experiments. The experiment tests are indoor and performed in Jordan with the halogen lamp bulbs with intensity of 915 W/m² is used and acted as a natural sunlight. The duration of the experiment is three hours for each test. Eexperimental tests are conducted to figure out the best cooling performance of the PV module. The results showed that the cooling channel with thickness of 5 cm and with volume low rate of 2 L/min is the best case for cooling. Without cooling the operating cell temperature reached the highest value of about 56°C. Using cooling with water, the reduction was 20.5% while, using cooling with glass porous media it reached up to 42.17%. The power of the module without cooling is reached the lowest value of 10.69 W and with water cooling it reaches 11.42W with percentage increase of (7.48%), while cooling with porous media, the power increases up to 12.07W with a percentage increase f (5.11%) and (12.9%) compared with water cooling and without cooling respectively.

KEYWORDS: PV Panel, Efficiency, Water cooling, Porous Media, Operating Temperature & Indoor Test

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Original Article

1 INTRODUCTION

In most of the word energy depends depend on fossil. Enormous consumption lead to exhaustion of these resources and currently fossil fuel like oil, gas and coal are the main energy sources, but these sources of energy are exhaustible and they will exhaust after some years. Jordan severely lacks enough sources of energy; which causes a decline in its economic level; this is due to the high cost of production of electricity using imported fossil fuels **[1].** The location of Jordan imposes us to think about the possible use of solar energy applications; Jordan has a very renewable energy, especially in solar energy, where the daily sun radiation is about 5-8 hours, which is considered to be one of the highest in the word **[2].** Use of solar energy for electricity production is safe, renewable, clean to the atmosphere and economic.

One of the major problems in the production of electric power through the use of photovoltaic is the cell overheating, which rising an average surface temperature of PV cell and consequently decreases the

efficiency. To maintain desired operation temperature of PV cells and to work under maximum performance, cooling-system must be added to the PV cells.

Many researchers have studied and found various techniques for cooling PV systems, so its performance and efficiency will increase. Among these studies, the work carried out by **M. Elhady et al., [3]**, used natural convection technique by drilling holes in PV panels to assist increasing temperature of the hot boundary layer in panels which cause to reduce its temperature. To reduce the temperature more, can increase the holes in panels and its diameter, the results showed that the temperature difference was depended on number of holes its reach its max on 12 holes by 19^{o}C. **S. Wu et al., [4]**, investigated cooling of PV module by using cooling channel above PV panel and analyzed the influence of mass flow rate. Inlet and outlet water temperatures and cooling channel height to study how they affect heat transfer characteristics and performance of PV module.

Nomenclature

Nomenclature	
A	Surface area, m^2
b	Breadth, m
Cp	Specific1 heat at constant pressure, J/kgk
EVA	Ethyl vinyl acetate
h	Heat transfer coefficient, W/m^{2}k
G	Solar intensity, W/m^2
k	Thermal conductivity, W/m k
L	Length, m
Qu	Rate of useful energy transfer, W
t	Time, s
T	Temperature, ^{O}C
Subscripts	
bs	back surface of tedlar1
c	solar cell
eff1	effective
fi1	inlet water
G	glass
i	Insulation1
ref1	reference
w	water
T	Tedlar1
th	thermal
Greek letter	
α	Absorptivity1
β	Packing factor
ŋ	Efficiency
τ	Transmissivity1

L. Idoko et al.,[5], used multi-concept cooling technique method which includes many varieties of cooling, cooling by water and air cooling. The results showed that the temperature of surface reduction and therefore the electrical efficiency is augmented up to 3%. **S. Golzari, et al., [6]**, investigated experimentally enhancement in heat transfer by the electro- hydrodynamics (EHD) through a single-pass air-cooled PV/T (Photovoltaic/Thermal System). So that the heat transfer coefficient is increased by 65% and the thermal efficiency of the PV/T system was increased up to 28.9%. **A. Castanheira et al., [7]**, studied the condition which affects the cooling kit system for existing and already working PV plants. They studied how they can minimize its cost and the amount of water used. **S. Jamali et al., [8]**, applied the solar

chimney system to cool semi-transparent photovoltaic (STPV) system. The STPV is to be placed in the lower of the solar chimney and an air flow generated by the solar chimney cools the STPV. The result showed a drop in average temperature and an increased in power generation up to 29%. **U. Rajput. et al., [9]**, explored the influence of a cylindrical pen fin heat sink and collector on reducing a PV cell's temperature. Temperatures reduced up to 58.4 °C with heat sink, while reduced to 47.9° using the collector. **F. Selimefendigila et al., [10]**, studied how porous fins can improve the efficiency of PV cells, so they built a PV module including porous fins and they realized that they can enhance the performance of the PV cells under specific conditions**.** H. **Kazem [11]** water-based photovoltaic / thermal (PV / T) system

Where efficiency was increased by approx 6% **H. Alizadeh et al., [12]**, used single turn pulsating heat pipe simulation for PV cooling The results showed an increase in electrical power generated is by 18% compared without any cooling system. **B. Zilli et al., [13]**, investigated an effect of water cooling on a micro generation system of photovoltaic solar energy. They realized that the efficiency and power were increased 12.17% and 12.26% respectively in high level of irradiation. On the other hand, the efficiency and the power were increased by 9.09% and 8.48%, respectively, in low irradiation level. **Q. Yang, et al., [14]**, employed liquid desiccant cooling system (LDCS) to increase the performance of PV module. The efficiency was increased up to 50% when the solution (desiccant) temperature was 20 ^{o}C. **A. Kane et al., [16]**. attached thermoelectric module at the back of the PV cell to absorbing heat. The results was simulated in MATLAB. The temperature was reduced at a range of (6-26%), and efficiency was improved up to 18% (maximum). **O. Bendra, [17]**, analyzed the enhancement in PV cell's efficiency in a hot regions. Mathematical hybrid system was developed to detect the increasing of temperature. The temperature was cooled down by (35-45^{o}C) and enhancement in efficiency and power output were obtained**. Y. Wang et al., [19]**, Water was used to cool the solar cell as there was a drop in temperature**10^{o}C. M. Lucas et al., [20]**, used evaporative solar chimney as a coolant, the electrical efficiency enhanced up to range of 4.9- 7.6% in summer – Mediterranean claimant, and the module temperature is decreased below 30◦C. **J. Mojumder et al., [21]**, designed a prototype of PV collector with cooling fins, and they induced air as a working fluid. They realized that thermal efficiency was increased in a range of 28.1-56.19%. **A. Aldossary et al., [22]**, used a method based on two heat sinks cooling systems with a water passes between these two sinks. They realized that the temperature was reduced by 14^{o}C, while the electrical efficiency was increased up to 39.5%. **R. Stropniket et al., [23]**, used PCM (phase change material) method to improve the PV panel. According to experimental results, the PV panel's temperature was decreased down to 35.6^{o}C, while the out power was increased by 4.3-8.7%, and its efficiency was increased by 0.5-1% comparing with conventional PV panel**. A. Amelia et al., [24]**, installed cooling mechanisms (4 DC Fans) at PV panel. The average temperature was decreased by 22.22%, and the power output was increased from first fan to the fourth 12.93, 37.17, 41.28, 44.34% respectively. **S. Nižetić et al., [25]**, investigated one of most common ways of cooling PV panels' surface by using spray water which gave an increase in the electrical efficiency and output power.

In this paper, the cooling of PV module will be investigated through cooling channel packed with porous media. Three different thicknesses for cooling channel with three different water volume flow rates will be used to investigate the best performance of the PV panel.

2. MATHEMATICAL FORMULATION

Formulation of the problems will be based on the following assumptions

- The transmissivity factor of Ethyl Vinyl Acetate material is almost 1.
- Temperature over each layer is considered to be the mean temperature.

- Uniform water steam between the insulation and the tedlar.
- Resistances are independent of both solar radiation and temperature.
- Limited shunt resistance depends on radiation and ignored with of temperature.

Thermal and electrical models as coupled model has been formulated to analyze different parameters associated with the performance PV/T hybrid system cooled by porous media. Initial segment involves depicts the thermal and electrical models.

2.1 Mmodelling of Thermal System

The thermal model is anticipated to assess the parameters, for example, cell temperature, A schematic outline of the PV-porous media cooled framework is depicted in Figure 1. Composing energy balance formulas for the parts in the integrated PV/T framework in particular back surface of the tedlar, PV module, and water flow beneath the tedlar, the governing conditions results for cell temperature, back surface temperature, Some details of the below equations are found in Refs. [26, 27]. The energy balance is used to obtain the back surface temperature of the module, the cell temperature as found in Eqs. (1) and (2), [28], The design parameters values utilized in this investigation are given in Table1.

$$T_{bs} = \frac{h_{p1}(\alpha\tau)_{eff} G + U_{tT} T_a + h_w T_w}{U_{tT} + h_w} (0.7 - e^{\frac{kd}{mcp}}) \tag{1}$$

$$T_c = [\frac{\tau_G[\alpha_c \beta_c + \alpha_T (1-\beta_c) G - \eta_c G \beta_c + U_t T_a + U_T T_{bs}}{U_t + U_T}] \tag{2}$$

$$Q_u = \frac{h_{p1} h_{p2} (\alpha\tau) eff G - U_L (T_W - T_a)}{U_L} (1 - e^{-bLU_L / \dot{m}cp}) \tag{3}$$

$$\eta_{th} = \frac{Q_u}{AG} \tag{4}$$

Where T_{bs} back surface temperature for PV, k is the thermal conductivity and d is the diameter of the porous media, T_C temperature of the frontal cell, Q_u thermal gain and η_{th} thermal efficiency.

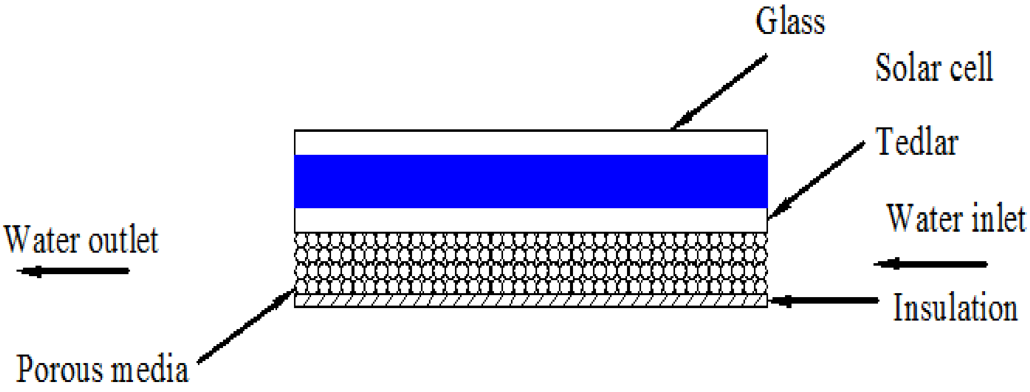

Figure 1:Details of PV Cooling Channel with Porous Media

Where UL a coefficient of heat transfer from cell to outdoor, through top and back, Ut a coefficient of heat transfer from solar cell to outdoor through glass, UT a coefficient of heat transfer from water to solar cell, Utw a coefficient of heat transfer from water to glass and Ub a coefficient of heat transfer from outdoor to back, a coefficient of heat transfer will be represented by the following Eqs. (5–9), [26]

$$U_L = U_{tw} + U_b \tag{5}$$

$$U_t = \left[\frac{L_G}{K_G} + \frac{1}{h_o} \right]^{-1} \tag{6}$$

$$U_T = \frac{K_T}{L_T} \tag{7}$$

$$U_{tw} = \frac{h_T U_{tT}}{U_{tT} + h_T} \tag{8}$$

$$U_b = \left[\frac{L_i}{K_i} + \frac{1}{h_i} \right]^{-1} \tag{9}$$

The parameters $(\alpha\tau)_{eff}$ represents an effective transmittance-absorptance product and given by Eq.(10), h_{p1} is the penalty factor due to the presence of cell materials, glass and EVA. h_{p2} is the penalty issue due to the presence of interface between water passing on the cell surface from the back and tedlars and are given by Eqs.(11) and(12), [26]

$$(\alpha\tau)_{eff} = \tau_G \left[\alpha_c \beta_c + \alpha_T (1 - \beta_c) - \eta_c \beta_c \right] \tag{10}$$

$$h_{p1} = \frac{U_T}{U_t + U_T} \tag{11}$$

$$h_{p2} = \frac{h_w}{U_{tT} + h_w} \tag{12}$$

Table 1: Design Values used in the Experiments

k_G(W/m K)	1	b(m)	0.355
k_i (W/m K)	0.35	CP(J/kg K)	4190
k_T (W/m K)	0.033	hi (W/m^2 K)	5.8
k_c	0.039	ho (W/m^2 K)	5.7+3.8V
L_c	0.0003	α_T	0.5
L_i	0.05	τ_G	0.9025
Lg (m)	0.003	α_c	0.90
L_T (m)	0.0005	β_c	0.90
Ac(m)	0.193475	η_c	0.155

2.2 Modeling of Electrical System

The term $(\alpha\tau)_{eff}$ showing in Eq. (10) represents an electrical efficiency and demonstrates that, the electrical and thermal examinations are depend on one another. To calculate the electrical efficiency, the values of maximum power voltage; current and power should be known prior. Therefore, an electrical model is used to approximate all involving parameters. Figure 2 shows an equivalent circuit of a photovoltaic cell. A photovoltaic module is characterized by (I-V) current voltage curve. In this analysis, the five-parameter model proposed by [28] is used for evaluating the parameters involving in electrical model system.

$$I = I_L - I_O\left[\exp\left(\frac{V + IR_S}{a}\right) - 1\right] - \frac{V + IR_S}{R_{Sh}} \quad (13)$$

$$I_{SC,ref} = I_{L,ref} - I_{O,ref}\left[\exp\left(\frac{I_{sc,ref}R_{s,ref}}{a_{ref}}\right) - 1\right] - \left(\frac{I_{sc,ref}R_{s,ref}}{R_{sh,ref}}\right) \quad (14)$$

$$I_{mp,ref} = I_{L,ref} - I_{O,ref}\left[\exp\left(\frac{V_{mp,ref} + I_{mp,ref}R_{s,ref}}{a_{ref}}\right) - 1\right] - \left(\frac{V_{mp,ref} + I_{mp,ref}R_{s,ref}}{R_{sh,ref}}\right) \quad (15)$$

$$I = I_L - I_O\left[\exp\left(\frac{V + IR_S}{a}\right) - 1\right] - \frac{V + IR_S}{R_{sh}} \quad (16)$$

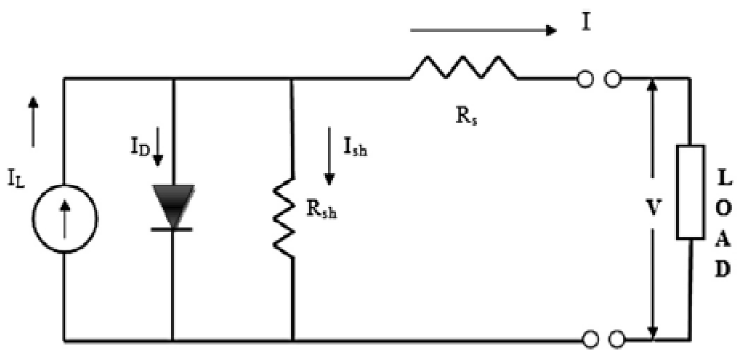

Figure 2: Equivalent Circuit of a PV Cell, [26]

Table 2: Standard Conditions Known at Three I-V Points on the Curve

Point	Conditions
Short circuit current	$I = I_{sh}, V = 0$ $[dI/dV]_{sc} = \frac{-1}{R_{sh,ref}}$
Open circuit voltage	$I = I_{sh} = 0, V = V_{OC,ref}$
Maximum power	$I = I_{\max,ref}, V = V_{\max,ref}$ $[d(IV)/dV]_{\max} = 0$

$$\frac{I_{mp,ref}}{V_{mp,ref}}=\frac{\left(\frac{I_{O,ref}}{a_{ref}}\right)\exp\left(\frac{V_{mp,ref}+I_{mp,ref}R_{s,ref}}{a_{ref}}\right)+\frac{1}{R_{sh,ref}}}{1+\left(\frac{I_{O,ref}R_{s,ref}}{a_{ref}}\right)\exp\left(\frac{V_{mp,ref}+I_{mp,ref}R_{s,ref}}{a_{ref}}\right)+\frac{R_{s,ref}}{R_{sh,ref}}} \tag{17}$$

$$\frac{a}{a_{ref}}=\frac{T_C}{T_{c,ref}} \tag{18}$$

$$I_L=\frac{S}{S_{ref}}\left[I_{L,ref}+\mu I_{sc}\left(T_C-T_{C,ref}\right)\right] \tag{19}$$

$$\frac{S}{S_{ref}}=M\left(\frac{G_b}{G_{ref}}RK_{\tau\alpha,b}+\frac{G_d}{G_{ref}}K_{\tau\alpha,d}\left(\frac{1+\cos(\beta)}{2}\right)+\frac{G}{G_{ref}}\rho_g K_{\tau\alpha,g}\left(\frac{1-\cos(\beta)}{2}\right)\right) \tag{20}$$

$$I_O=I_{oref}\left(\frac{T_C}{T_{C,ref}}\right)^3\exp\left(\frac{\varepsilon}{KT_{C,ref}}-\frac{\varepsilon}{KT_C}\right) \tag{21}$$

$$\frac{R_{sh}}{R_{sh,ref}}=\frac{S_{ref}}{S} \tag{22}$$

Solving Equations (18–22) gives values at reference conditions. Next, the operational values I_{mp} and V_{mp} can be found from Equations (23–26), [28].

$$\frac{I_{mp}}{V_{mp}}=\left[\frac{\frac{I_O}{a}\exp\left(\frac{V_{mp}+I_{mp}R_s}{a}\right)+\frac{1}{R_{sh}}}{1+\frac{R_s}{R_{sh}}+\frac{I_oR_s}{a}\exp\left(\frac{V_{mp}+I_{mp}R_s}{a}\right)}\right] \tag{23}$$

$$I_{mp}=I_L-I_O\left[\exp\left(\frac{V_{mp}+I_{mp}R_S}{a}\right)-1\right]-\left[\frac{V_{mp}+I_{mp}R_S}{R_{sh}}\right] \tag{24}$$

The maximum power $P_{\max}$ and efficiency η_c can be found as follows:

$$P_{\max}=I_{\max}V_{\max} \tag{25}$$

$$\eta_c=\frac{I_{\max}V_{\max}}{A_cG} \tag{26}$$

3. EXPERIMENTAL SETUP

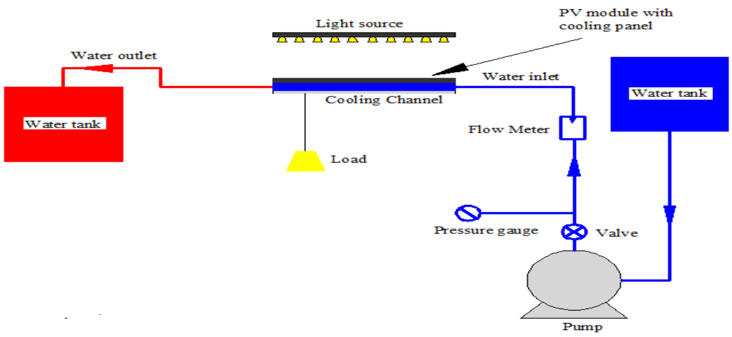

Figure 3: Schematic Diagram for Experimental Setup

Figure 3 shows schematic diagram for experimental setup.

Solar simulator capable for giving repeated solar radiation at any time and any climate. The solar radiation value has been constant over the duration of the experiment. Figure 4 shows a solar simulator where was used fifty halogen lamps 50W, 220V in solar simulator, In order to get average radiation value of 915W/m^2 at the height of the bulbs above the cell 50cm is used. To obtain and utilize a high-intensity it is necessary to adjust the panel to high temperatures as those of the literature reviewed concerning concentrating Photo voltaics, **[28].** The function of the simulator was illuminating a wood surface. The lights of halogen were adjusted to get the most regular and uniform temperatures on the wood surface that reflect the best possible uniform irradiance due to wood low thermal conductivity. Adjustments to the halogen light fixture were made and the lighting of each lamp is controlled individually; to achieve the temperature non- uniformity within value no more than 5.2%, which was characterized as class B uniformity of radiation. **Q. Meng et al.,[29]**, showed that the requirements of indoor test regarding the solar radiation area in the solar simulator should be larger than the PV area. This condition was satisfied in all experiments and a non-uniformity of radiation was calculated to be 3.5 % from equation (27), **[29]**.

$$\text{Non - uniformity } (\%) = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} * 100\% \tag{27}$$

Where E_{max} is maximum radiation above solar cell and $E_{min.}$ is minimum radiation above solar cell.

Figure 4: Solar Simulator

3.1 Ssetup of Cooling System

Figure 5: Solar Thermal Cooling Channel

Table 3: PV Specifications

Solar PV Module Parameter	**Value at AM 1.5 Spectra STC[1]**	**Value at Halogen Light[2]**
Maximum power, P_{max}	30W	13.24W
Open -circuit voltage, V_{oc}	22V	22V
Short -circuit current, I_{sc}	1.84A	0.92A
Voltage at P_{max}	18V	16V
Current at P_{max}	1.67A	0. 84A
Operating temperature, ^oC	-40 to+85	-40 to+85
Dimensions	(545x355)cm	(545x355)cm
Radiation intensity, G	1000 W/m^2	915 W/m^2

[1] Values refer to (standard test conditions) with T_{cell}=25°C, 1000W/m^2 and 1.5 AM spectra.
[2] Values refer to the present study conditions with Ta = 20°C and zero m/s wind speed under halogen light.

The experimental setup represents a hybrid system. It comprises of a PV module (poly-crystalline type 30W rated power) combined with a solar thermal collector as shown in Figure 5. The cooling channel (collector) is packed with porous media, equipped with inlet/outlet ports for the water flow and attached to the back side of the solar panel. Dimensions of channel are the same dimensions of the PV module. Three collectors with three different thicknesses 3cm, 5cm and 7cm are used and installed on the back side of photovoltaic cells. These channels filled with glass porous media of diameter (10mm) and the water was pumped through the cooling channel with three different volume flow rates of 1L/min, 1.5L/min and 2L/min.

The specifications of the PV module used are given in Tables 3. The cooling water comes from tanks connected to the PV/T system through plastic tubes. A water pumps (0.5 hp) are used to recycle water through the cooling channel. Flow meter with maximum volume flow rate of 2 L/min is used to regulate the water flow rate inside the cooling channel. During flowing of water inside the cooling channel, it takes the waste heat from the PV module and heats the water inside the collector and finally, the hot water collected at the collector outlet. Standard type-thermocouples are attached at the inlet and outlet of the collector to measure the inlet and outlet water temperatures.

4 SETUP OF ELECTRICAL MODEL

An electrical setup was used to measure the module performance. It consists of thermocouple, voltmeter, ammeter and solar intensity meter. Module surface front temperatures were measured by thermocouple at three locations and the average was taken. The instruments used in measurements are shown in Figures 6-10. The value of accurateness/ sensitivity of the used devices are given in Table 4.

Table 4: The Accurateness/ Sensitivity of the used Devices

Device	Accurateness/ Sensitivity
Solar power meter	$10W/m^2$
Volte meter and ammeter	1mV
Thermocouple	$\pm 0.5^{O}C$

Figure 6: Volt Meter

Figure 7: Flow Meter

Figure 8: Solar Intensity

Figure 9: Solar Pump

Figure 10: Data Logger

5 RESULTS AND DISCUSSIONS

The results of the indoor experimental tests for best performance of the PV module using cooling channel with three thicknesses 3, 5 and 7 cm packed with porous media for three volume flow rates 1 L/min, 1.5 L/min and 2 L/min and the duration of each experiment test was three hours are obtained. Figure 11 shows the comparison in cell average temperature between PV cells without cooling and cooling with water and with porous media for cooling channel thickness of 3 cm and volume flow rate 1L/min during the period of the test. It is clear that, the temperature rises gradually in the three cases. Without cooling the cell average temperature reached the highest value, it was about 56^{o}C. Cooling the module with water resulted in the reduction in average cells temperature down to 47.9 ^{o}C, while using cooling with glass porous media; the temperature was reduced down to 37.7 ^{o}C. The percentage reduction in average cells temperature was 32.6%, while this percentage reduction was increased up to35.6 % for volume flow rate of 1.5 L/min and35.7% for volume flow rate of 2 L/min as shown in Figures 12 and 13 respectively.

Find a percentage the reduction of temperature and power increase from Eq. (28) and (29) **N. Karami [30]**

$$\%T_{\max,increase} = \frac{T_{withoutcooling} - T_{cooling}}{T_{withoutcooling}} * 100\% \tag{28}$$

$$\%P_{\max,increase} = \frac{P_{cooling} - P_{withoutcooling}}{P_{withoutcooling}} * 100\% \tag{29}$$

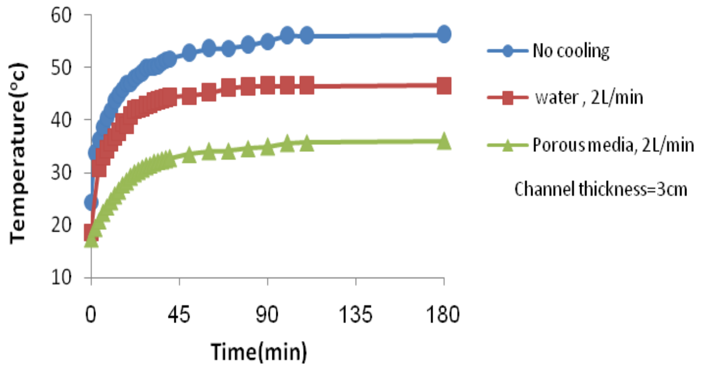

Figure 11: Comparison of an Average Temperature with no Cooling, Cooling with Water and Cooling with Porous Media for Channel Thichness=3 Cm and Volume Flow Rate=1 L/Min

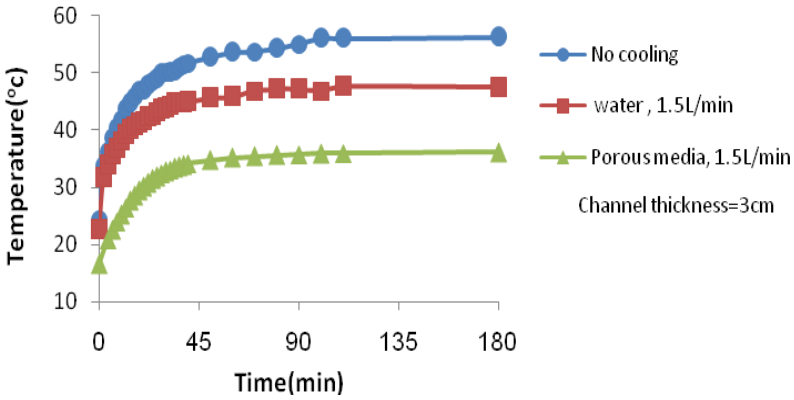

Figure 12: Comparison of an Average Temperature with no Cooling, Cooling with Water and Cooling with Porous Media for Channel Thichness=3 Cm and Volume Flow Rate=1.5 L/Min

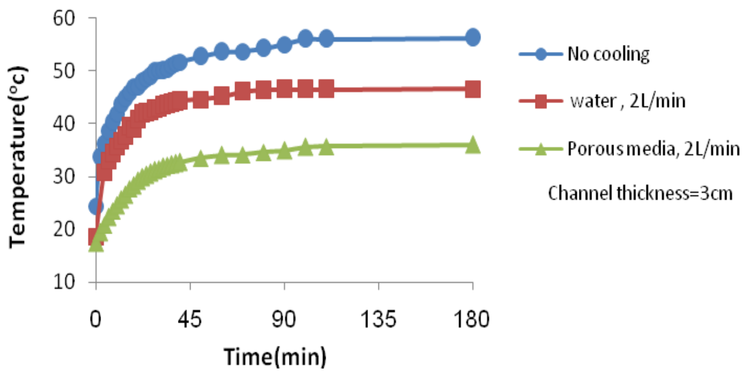

Figure 13: Comparison of an Average Temperature with No Cooling, Cooling with Water and Cooling with Porous Media for Channel Thichness=3 Cm and Volume Flow Rate=2 L/Min.

The same trends of an average temperature reduction in PV cells were observed with channel of thickness 5 cm, as shown in Figure 14. Again, the percentage reduction in average cells temperature was 39.2%, while this percentage reduction was increased up to 40.17% for flow rate of 1.5 L/min and 42.18% for flow rate of 2 L/min as shown in Figures 15 and 16.

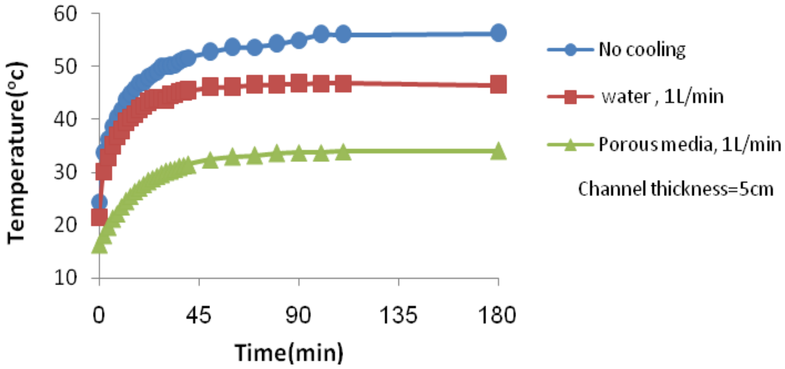

Figure 14: Comparison of an Average Temperature with No Cooling, Cooling with Water and Cooling with Porous Media for Channel Thickness=5 Cm and F Volume Low Rate=1 L/Min

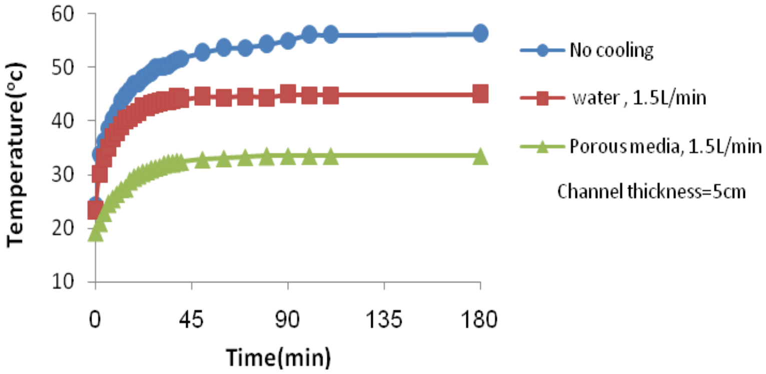

Figure 15: Comparison of an Average Temperature with no Cooling, Cooling with Water and Cooling with Porous Media for Channel Thichness=5 Cm and Volume Flow Rate=1.5 L/Min

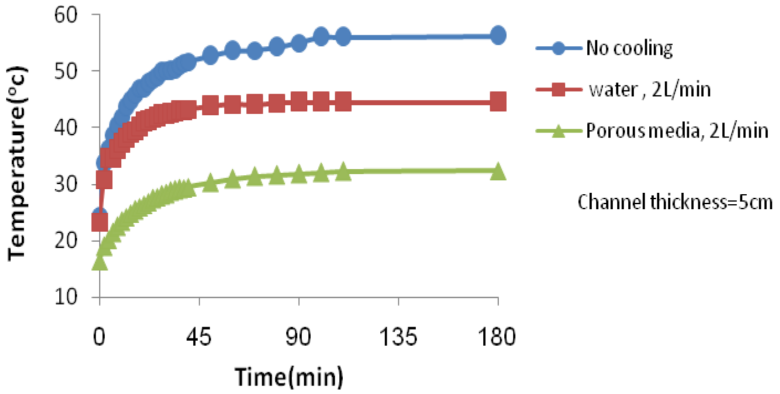

Figure 16: Comparison of an Average Temperature with no Cooling, Cooling with Water and Cooling with Porous Media for Channel Thichness=5 Cm and Volume Flow Rate=2 L/Min

The same trends of an average temperature reduction in PV cells were observed with channel of thickness 7 cm, as shown in Figure 17. Again, the percentage reduction in average cells temperature was 34%, while this percentage reduction was increased up to 34.6% for flow rate of 1.5 L/min and 35.4% for flow rate of 2 L/min as shown in Figures 18 and 19.

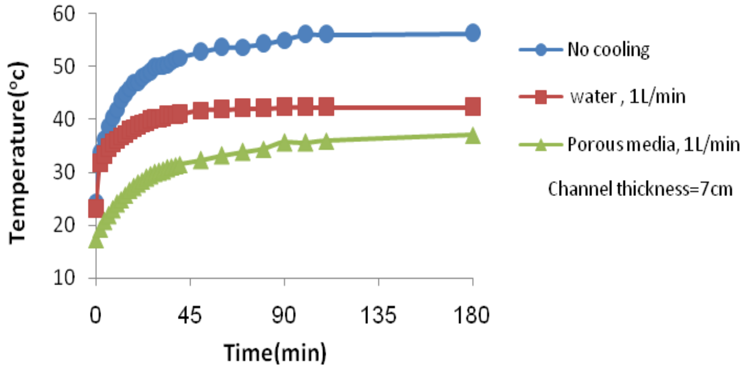

Figure 17: Comparison of an Average Temperature with no Cooling, Cooling with Water and Cooling with Porous Media for Channel Thichness=7 Cm and Volume Flow Rate=1 L/Min

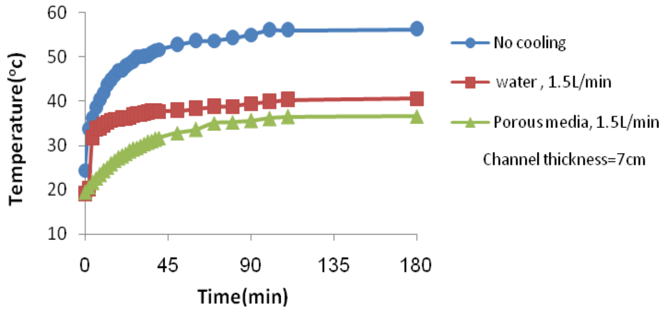

Figure 18: Comparison of an Average Temperature with no Cooling, Cooling with Water and Cooling with Porous Media for Channel Thichness=7 Cm and Volume Flow Rate=1.5 L/Min

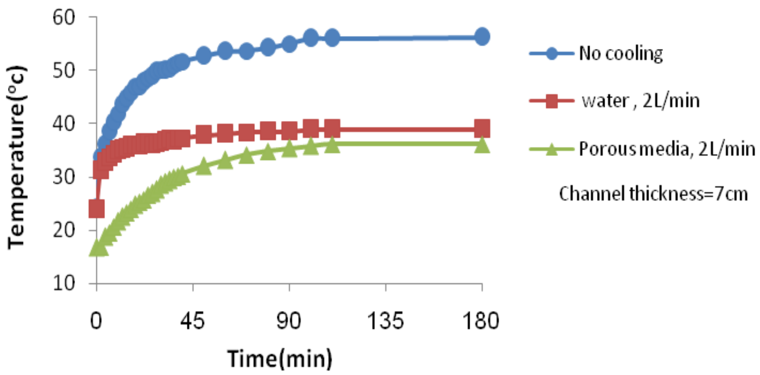

Figure 19: Comparison of an Average Temperature with No Cooling, Cooling with Water and Cooling with Porous Media for Channel Thichness=7 Cm and Volume Flow Rate=2 L/Min

The performance of PV module under different cooling channel thicknesses 3, 5 and 7 cm with different flow rates, 1, 1.5 and 2 L/min are examined in Figures 20, 21 and 22. It is obvious from the figures that the channel thickness of 5 cm is the best among all others for all flow rates, its reduction in average cells temperature is more pronounced and reached up to 42.17 % for volume flow rate of 2 L/min. Therefore, the best performance of PV module under cooling with porous media is the case with cooling channel thickness of 5 cm and flow rate of 2 L/min as shown in Figure 23. The percentage reduction in average temperature was 20.5% with water cooling, while reduced up to 42.17% by using porous media.

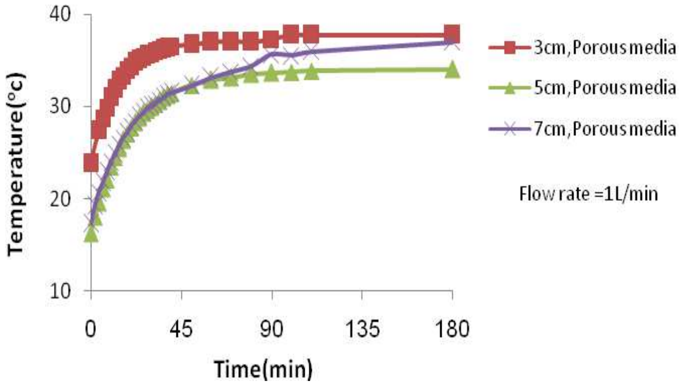

Figure 20: Comparison of an Averge Temperature for Different Channel Thicknesses with Volume Flow Rate of 1 L/Min

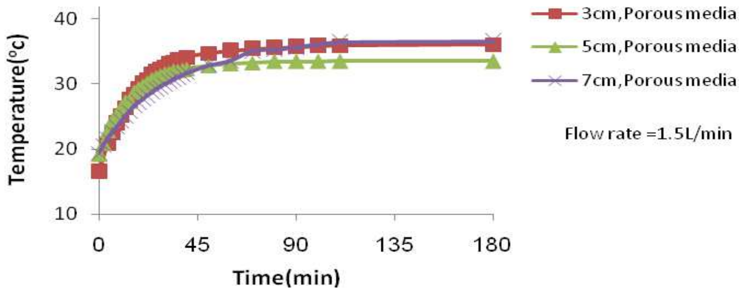

Figure 21: Comparison of an Average Temperature for Different Channel Thicknesses with Volume Flow Rate of 1.5 L/Min

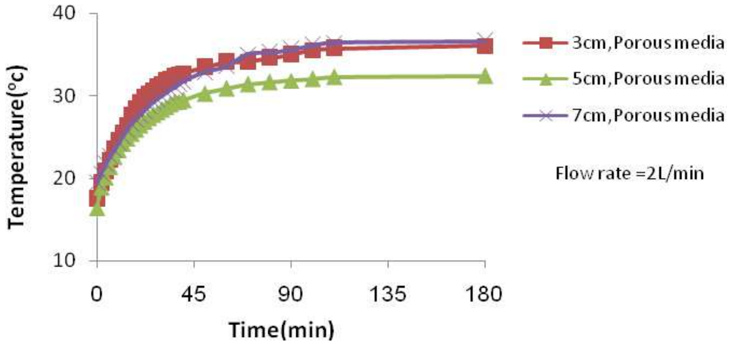

Figure 22: Comparison of an Average Temperature for Different Channel Thicknesses with Volume Flow Rate of 2 L/Min

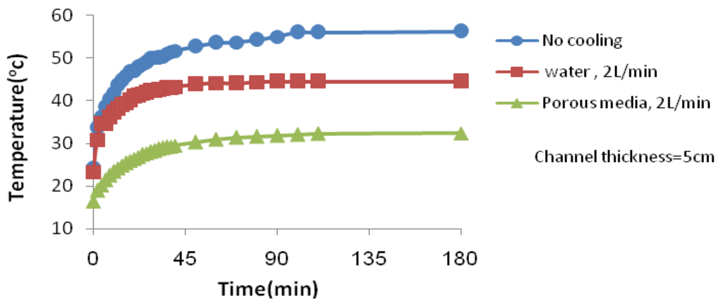

Figure 23: Comparison of an Average Temperature with no Cooling, Cooling with Water and Cooling with Porous Media for Best Performance

The corresponding enhancement in power of PV module for the best case is shown in Figure 24. The power of the module without cooling reached the lowest value of 10.69 W and with water cooling it reaches 11.48 with percentage increase of 7.4%, while cooling with porous media, the power increases up to 12.07W with a percentage increase of 5.11% and 12.9% compared with water cooling and without cooling respectively. Figure 24 displays the comparison of efficiencies for PV module without cooling, cooling with water and cooling with porous media. it is observed that the cooling with porous media gives the best efficiency among the others. The efficiency of the PV module without cooling is 6.04% and with cooling it reaches 6.4% while cooling with porous media reaches 6.8%. The percentage increases in efficiency between water cooling and cooling with porous media is about (5.11%).

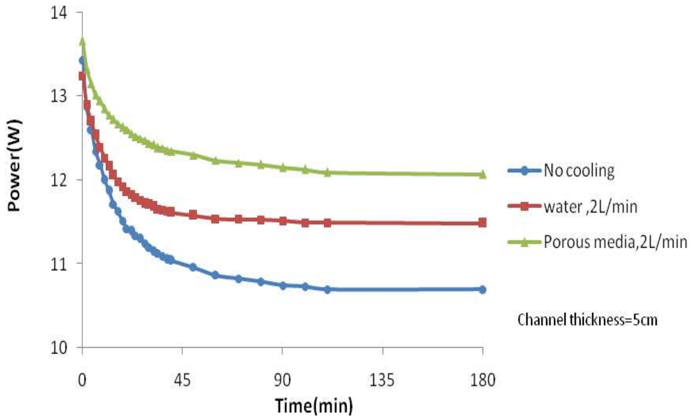

Figure 24: Comparison of Powers with no Cooling, Cooling with Water and Cooling with Porous Media for Best Performance at Channel Thickness 5cm

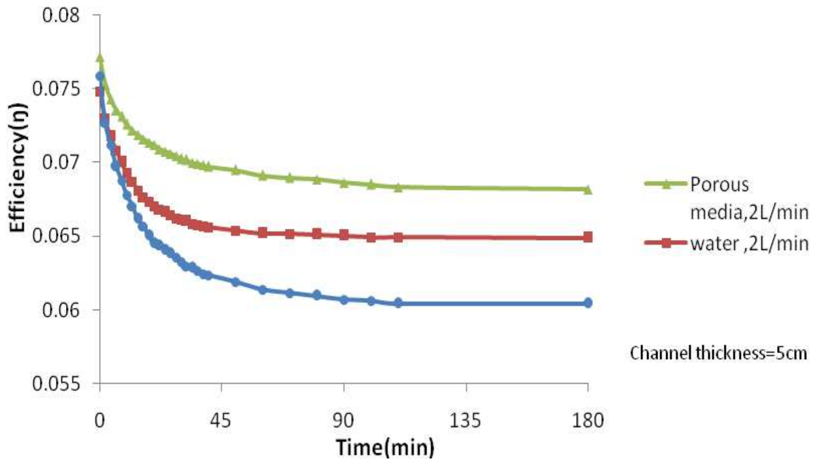

Figure 25: Comparison of Efficiencies with no Cooling, Cooling with Water and Cooling with Porous Media for Best Performance at Channel Thickness 5cm

Table 5: Comparison of Reduction in Temperature and Increasing in Power with Previous Work.

Previous work	Coolant used	Increasing in Power	Reducing in Temperature
Present work	Porous media	12.85%	42.18%
Ref.[31]	Nanofluid Tio_2	7.67%	27.43%
Ref.[32]	PCM	5.2%	up to 5 ^{o}C
Ref.[33]	Air	7.5%	6 ^{o}C

Table 5 shows a comparison in the temperature reduction and power increasing between the present work and cooling with nano fluid, PCM and air relative to without cooling. It is clear from the values of reduction in temperature and

increasing in power for different cooling media that, cooling with porous media is more effective than other media, this due to large exposed surface area in the case of porous media.

6 COMPARISON WITH NNUMERICAL RESULTS

The numerical model outcome results are compared with the experimental results. Generally, there are close match between the numerical and test results for module surface front temperature, efficiency and maximum power yield. Figure 26 shows a comparison between the numerical results and experimental of the PV average temperature. It is found that there is a close consensus between the results, based on the Equation (2), where the highest percentage error was 7%. Figure 27shows a decent understanding between the experimental test and for yield control, in view of the Equation (25), with the highest percentage error was 7.6 %. Thermal energy represents as an increase in the temperature of the outlet water. This indicates the increase in the PV temperature where there is a good agreement between experimental and numerical results, based on the Equation (3), where the highest percentage error was 7.6%

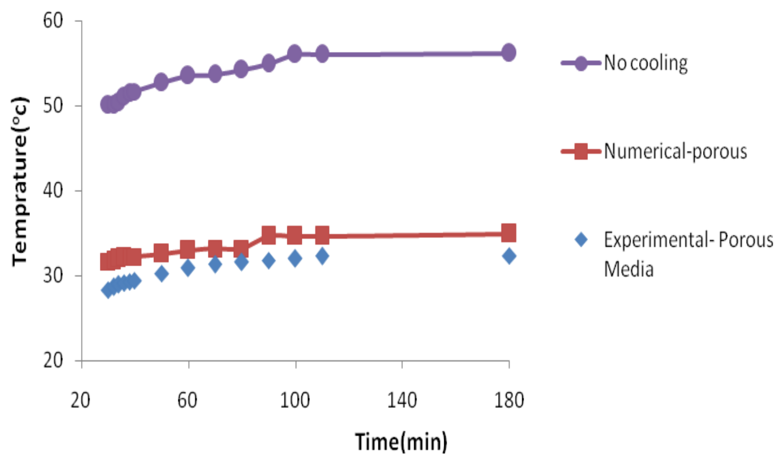

Figure 26: Comparison between the Results of an Average Temperature of Numerical, Experemental and Without Cooling for Best Module Performance (Collector Thickness=5cm and Volume Flow Rate=2L/Min)

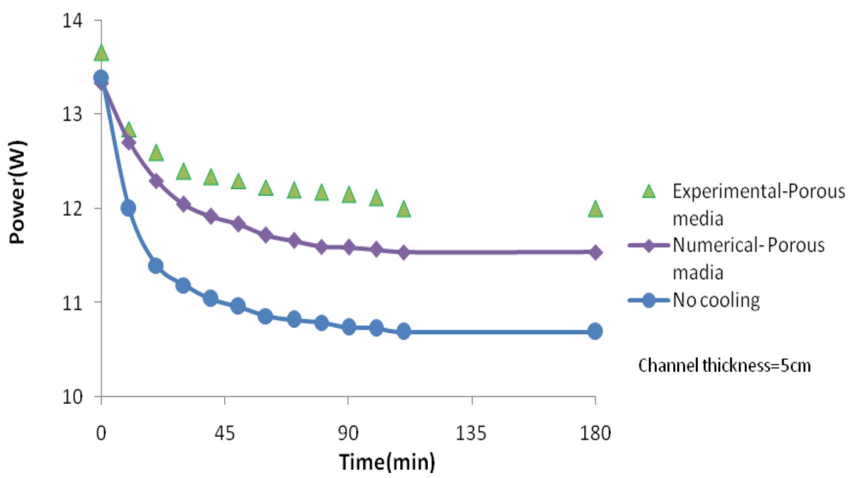

Figure 27: Comparison Between the Results of an Output Power of Numerical, Experemental and without Cooling for Best Module Performance (Collector Thickness=5cm and Volume Flow Rate=2L/Min)

7 CONCLUSIONS

Experimental and Numerical examination of a PV-porous media cooled hybrid framework was examined in regards to its thermal and electrical execution. A numerical model (coupled thermal and electrical) fit for predicting the electrical and thermal execution of the water cooled PV framework is created utilizing Matlab.

Experimental investigations of a PV module performance under different cooling channel thicknesses and volume flow rates were performed. According to the results obtained, the following conclusions may be made:

- The best performance of the PV module cooling with porous media is obtained with cooling channel thicknesses of 5 cm and with volume flow rate of 2 L/min.
- Without cooling the operating cell temperature reached the highest value of about 56^{o}C. Using cooling with water, the reduction in temperature was (20.5%) while, using cooling with glass porous media, the reduction reached up to (42.17%).
- The corresponding efficiency of the PV module without cooling was (6 %) while in case of porous media cooling reached up to (6.8%).
- Cooling with porous media is proved to be better than cooling water alone.

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